VISUALIZATION OF WEATHER-AWARE AMBIENT HEAT RISKS WITH GLOBAL ILLUMINATION IN GAME ENGINE

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ABSTRACT: *In recent years, the risk of heat stroke has been increasing due to global warming and other factors, and the Ministry of the Environment has been using the heat index to alert people in urban areas. Still, citizens need help knowing the detailed risk information for their neighborhoods. The heat index considers the human body's heat balance and is measured with specialized instruments, so comprehensive and high-density measurement is difficult. In this research, by using global illumination (GI) and primary weather data obtained from the Open Weather Map API for each area, we can realistically render the sunlight condition considering the weather and map and visualize the heat index per pixel based on shaded CG. Furthermore, by reconstructing urban 3D geometry from Google Maps, we have developed a system that visualizes the ever-changing heat index distribution for an arbitrary location in real time. The system has shown the possibility of reducing the number of heat stroke patients by using this system.*

KEYWORDS: *heat index, WBGT (wet bulb globe temperature), real-time global illumination, game engine*

1. INTRODUCTION

The number of heat stroke cases and deaths continues to increase in modern society due to the effects of severe climate change caused by global warming and the heat island effect (Ministry of Health, Labour and Welfare, 2013~2020).In particular, the proportion of heat stroke patients who suffer heat stroke when outside has reached approximately 60% of all cases (Ministry of Internal Affairs and Communications, 2022), and the possibility that heat stroke is not limited to certain times of the day is also increasing (Ministry of Health, Labour and Welfare, 2018-2022).In addition, the WBGT (Wet Bulb Globe Temperature), an indicator of heat stroke risk provided by the Ministry of the Environment, showed that the value in 2022 exceeded the average value of the previous ten years and that the upward trend is continuing (Ministry of the Environment, 2022). Daily life activities require outdoor maintenance and cleaning work, visits to neighborhood stores, etc., and from the viewpoint of health promotion, visits to parks have become habitual activities for a wide range of age groups (T. Ozaki et al., 2019). The Ministry of the Environment publishes WBGT values for each city on the Web to alert the public (Ministry of the Environment, 2023). However, as one WBGT value is assigned to a metropolitan area, the outdoor environment of each location, comprising different geographical features such as city blocks, parks, and construction sites, is not considered. Facility and site managers must accurately understand the environmental risks visitors and workers face. In addition, schools and other educational institutions are required to regularly measure WBGT before and during outdoor activities such as sports festivals and excursions to ascertain the level of risk so that classes and activities can be conducted more safely (Ministry of the Environment, Ministry of Education, Culture, Sports, Science and Technology, 2021). However, there are limitations to deploying a large number of WBGT measuring devices to collect information. Each individual needs to make decisions and respond based on their own experience. In this study, we propose a new method to visualize the distribution of heat index under sequential changes in the sunshine environment and provide it to general users by using regional meteorological data and 3DCG-based surface solar radiation estimation using global illumination (GI).

2. PREVIOUS WORK

2.1 Okada-Kusaka black-bulb temperature estimation formula

WBGT is an index focusing on the heat balance between the human body and the outside air and is calculated using equation (1), considering the surrounding thermal environment such as humidity, solar radiation, and air temperature. A black-bulb thermometer is required to measure radiant heat, but Okada et al. point out that it is difficult to measure the temperature stably and continuously. Therefore, Okada et al. estimated black-ball temperatures using total solar radiation, wind speed, and dry-ball temperature as explanatory variables (M. Okada et al., 2013). The estimation equation (2) enables the estimation of black-ball temperature from meteorological data on total solar radiation, wind speed, and dry-ball temperature, making it possible to calculate WBGT estimates not only for sunny days but also for a wide variety of weather conditions.

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$$WBGT = 0.7 \times Wet\ Bulb\ Temp. + 0.2 \times Black\ Bulb\ Temp. + 0.1 \times Dry\ Bulb\ Temp. \quad (1)$$

$$Black\ Bulb\ Temp. = \frac{Global\ Solar\ Radiation - 38.5}{0.0217 \times Global\ Solar\ Radiation + 4.35 \times Wind\ Speed + 23.5} + Dry\ Bulb\ Temp. \quad (2)$$

2.2 3DCG-Based Estimation Method of WBGT and Its Application

Yasumuro et al. proposed a method to estimate WBGT by optical calculation using GI for 3DCG rendering to visualize the effect of green shade against heat, as shown in Fig. 1(Y. Yasumuro et al., 2018). First, standard reflectors placed under various shades of green were photographed with a single-lens reflex camera at fixed exposures, and the pixel values were converted to absolute luminance values. On the other hand, the total solar irradiance at the position in the reflector corresponding to each pixel is also measured, and a linear regression analysis is used to determine the correlation between the absolute luminance and the total solar irradiance. WBGT can be estimated from Equation (1) by obtaining the black-bulb temperature using the estimation equation (2) of Okada et al. based on the total solar irradiance calculated using this correlation equation and primary meteorological data such as dry-bulb temperature, wet-bulb temperature, and wind speed, which indicate the conditions at the target location. Furthermore, Yasumuro et al. have made it possible to estimate WBGT without the need for on-site photography by realistically rendering shades using GI with CG that virtually sets the same reflectance characteristics as the standard reflector shown in Fig. 2. By preparing a 3D model of a landmark, it is possible to reproduce solar radiation conditions in 3DCG based on the latitude and longitude of the landmark and its position concerning the sun, making it possible to determine the heat-protection effect of green shade at any given time. In this research, the GI that reproduces photorealistic solar radiation conditions in CG requires a large amount of light path search, and the generation of CG takes time each time the conditions are changed.

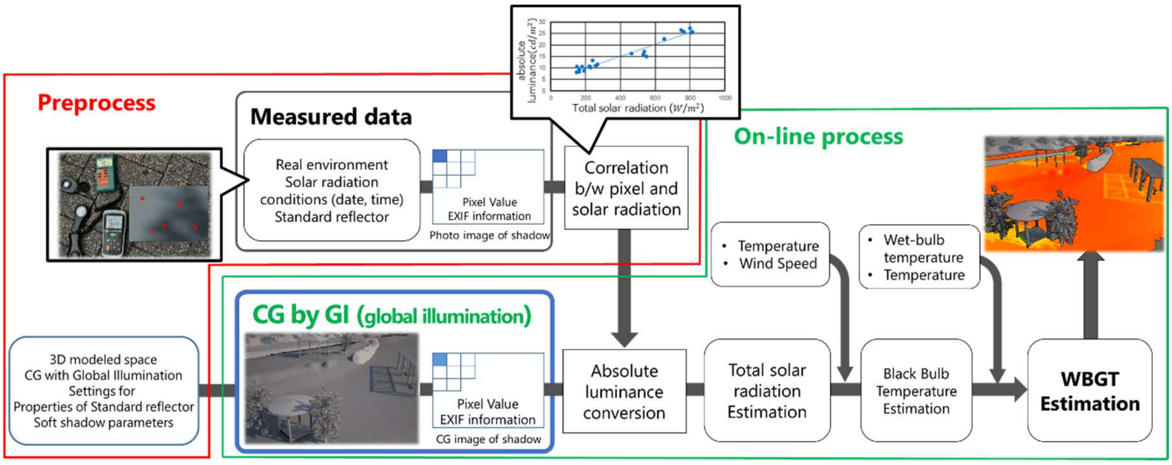

Fig. 1: Process chain for estimation of WBGT and visualization as heatmap image

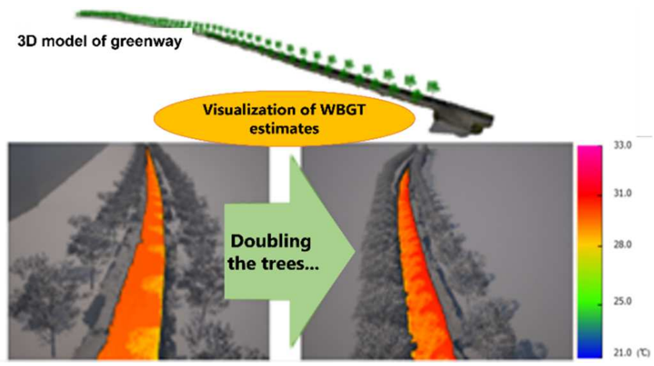

Fig. 2: Example of heat simulation of a greenway with varying plantings
(left: Current planting condition, right: Doubled planting condition)

2.3 Visualization of Environmental Heat Risks with Global Illumination in Game Engine

The authors proposed a method to visualize heat index distribution for ever-changing sunlight conditions regardless of location and stream it to general users on the Web by using a game engine utilizing real-time GI to speed up the generation of solar radiation CG by GI and developing a system to obtain basic weather information in real-time as shown in Fig. 3 and demonstrated the effectiveness of this function (N. Sumida et al., 2022). According to the estimated WBGT value, a function is implemented to visualize the risk of heat stroke as a multi-step heat map using CG by setting colors and interpolation processing using the UV coordinates of the texture based on the colors of the danger levels shown by the Ministry of the Environment in Fig. 4. Although the visualization results are provided universally to the user's terminal via a web browser, this method requires 3D data on the terrain covering the target area for generating CG, and there are many areas where 3D data are not publicly available, limiting the applicable target areas. In addition, the calculation of WBGT requires primary meteorological data for the area. Still, a system that can automatically collect and reference these by region and time needs to be solved. Systematization to solve these problems remains challenging to realize an information service that presents heat risks for any given location and time in response to user requests.

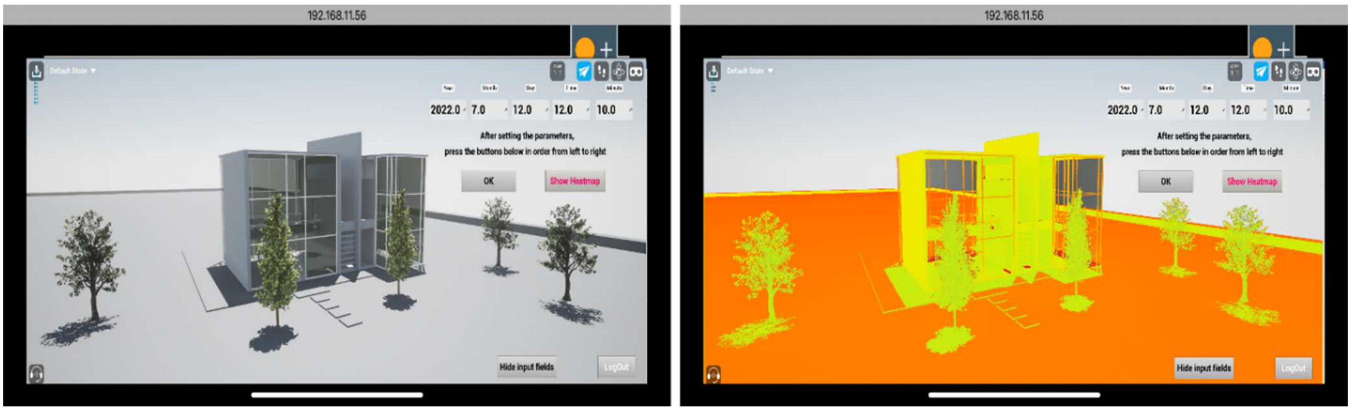

Fig. 3: CG of ground shading with standard diffuse reflection (left) and resultant WBGT heat map (right)

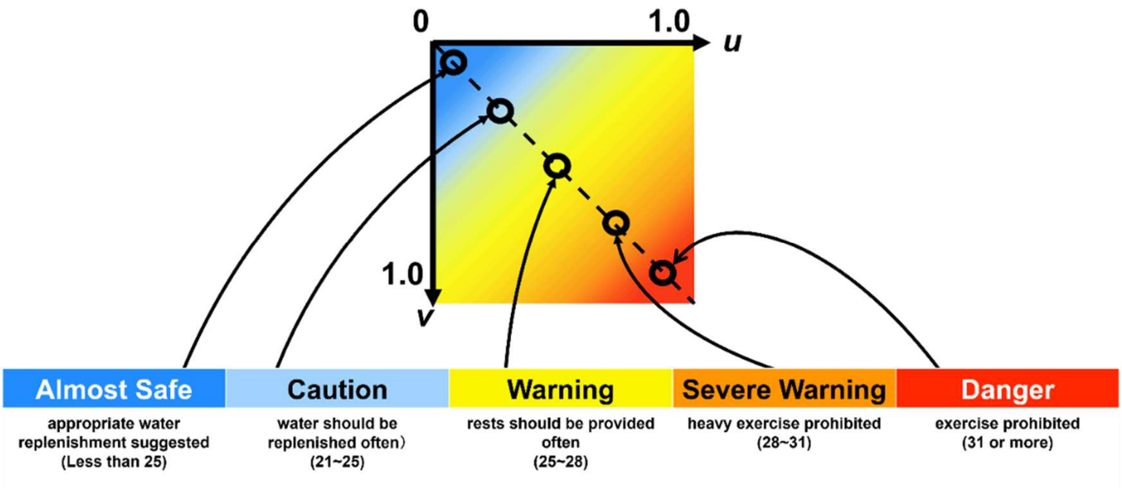

Fig. 4: U-V coordinate of the color texture based on Ministry of the Environment guidelines

3. PROPOSED METHOD

In this study, we propose a system that collects and utilizes necessary data by employing weather data services and 3D information services available on the Internet for an application server with a WBGT estimation function, which the authors have already constructed. Fig. 5 shows the processing procedure of the system proposed in this study. In the real-time GI used by the application server, many image data (called light probes) mapping light source information in all directions are placed in the target space, and information on many light ray paths, including inter-reflection by static objects such as buildings, is pre-calculated as textures. By tracing light probe information, the cost of calculating the synergistic effects of light rays can be significantly reduced, and high-quality computer graphics that include effects such as indirect light can be rendered in real-time. (SILVENNOINEN, A et al., 2017) (K. Kurachi. 2007). Although the target scenes of this study include complex shapes such as trees and buildings, dynamically changing geographic objects are not required, making the system suitable for introducing real-time GI. The user specifies the date, time, and location from a Web browser on the terminal at hand and accesses the application server via the network to use this application. The application server uses the date, time, and location information specified by the user as a query, extracts the corresponding weather data and 3D data from the database, generates CG of the sunshine conditions, and estimates WBGT. The weather data collection server automatically obtains weather information using weather data services provided through public APIs and sensor networks of instruments installed in the region. It stores the relevant information in the weather information database. The 3D data collection server automatically collects 3D data and material information of publicly available geographic objects and stores this information in a 3D model database. For areas where 3D data is not publicly available, a database is created by reconstructing 3D models from map services that can be viewed in 3D on the Internet. By designing the database with the data items required for WBGT calculation in the application server as attributes, data collected from different information sources can be effectively utilized. The 3D data collection server automatically collects 3D data and material information of publicly available geographic features and stores this information in the 3D model database. For areas where 3D data is not publicly available, a database is created by reconstructing 3D models from map services that can be viewed in 3D on the Internet. This system configuration is expected to increase the affinity with the information provided by other services already widely used as information infrastructure and extend the range of applications of this method.

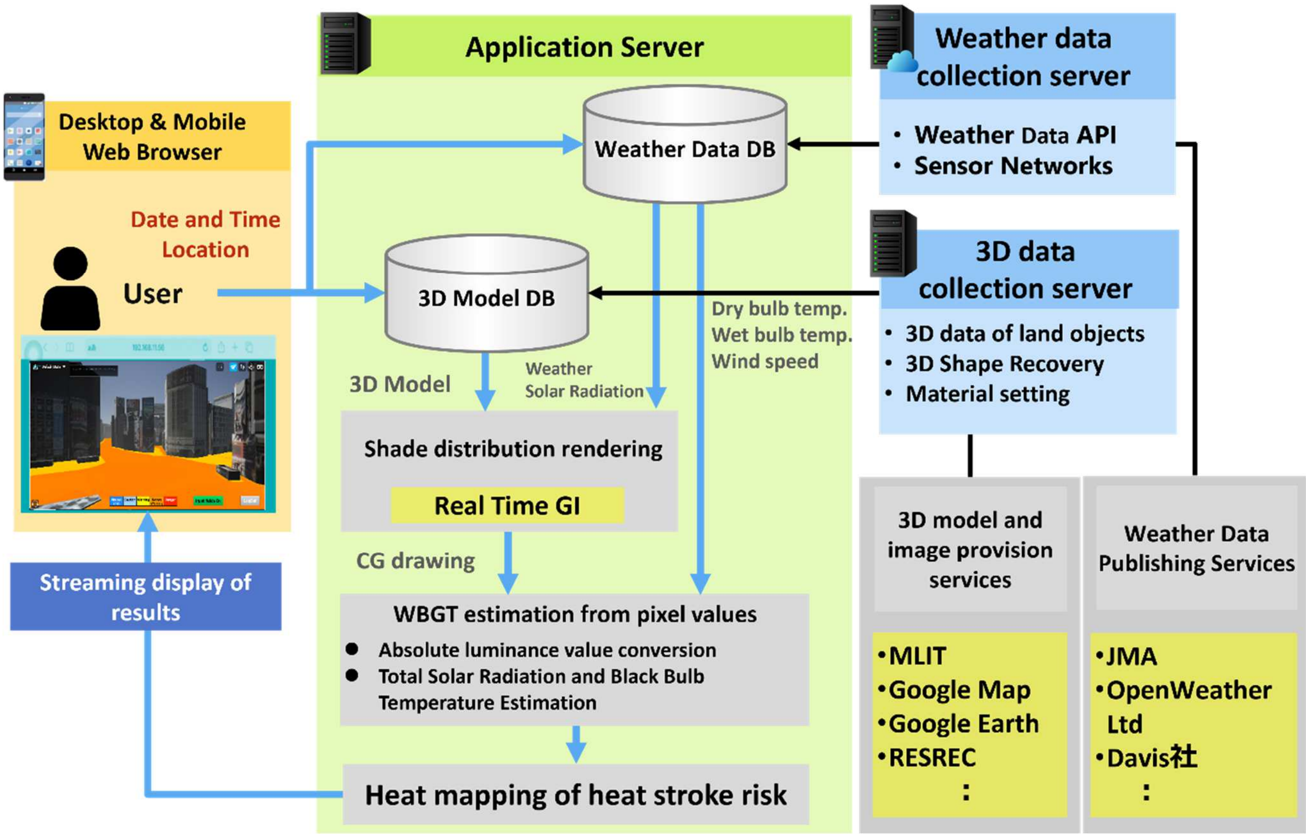

Fig. 5: Proposed System Process Chain

4. IMPLEMENTATION AND VERIFICATION

This study utilized Unreal Engine 4 (UE), a game development platform with real-time GI and sun placement functions based on geographic coordinates and functions equivalent to the exposure settings of a single-lens reflex camera, which can be used to generate realistic computer graphics. An input interface shown in Fig. 7 is implemented in the UE to allow users to select specific locations. After entering a place name, a button for selecting the corresponding place name is displayed. When the user clicks the button, the user is automatically redirected to a map showing 3D data of the corresponding area. When the user clicks on a button, the user is automatically redirected to a map displaying 3D data of the corresponding area. When the place name is searched by prefecture, all buttons for the corresponding city, town, or ward are listed and can be selected in a scrolling format. The method of setting the date and time and the output process of the heat map of WBGT distribution after setting the date and time are based on the authors' existing method.

The weather data collection server in the proposed system uses Open Weather Map API provided by Open Weather to obtain publicly available weather forecast data. Open Weather Map API is suitable for this study because it can provide basic weather information required for WBGT estimation, as well as information on specific locations and times required for CG generation using real-time GI. In addition, a DAVIS VantagePro2 sensor is used to collect real-time weather information at individual sites. The Open Weather Map API and the VantagePro2 are suitable for this study because they are commercially available and can be installed at individual sites. Considering that VantagePro2 sends data in Json format to the weather data collection server, as shown in Fig. 7, we implemented a parsing function in the application server UE to analyze the received Json data and sort them into attributes suitable for this system. This implementation makes it possible to comprehensively process the acquired information and convert it into a format suitable for the proposed system, even when the data sources differ.

Fig. 6: Pull-down menu interface for selecting location incorporated in the game engine

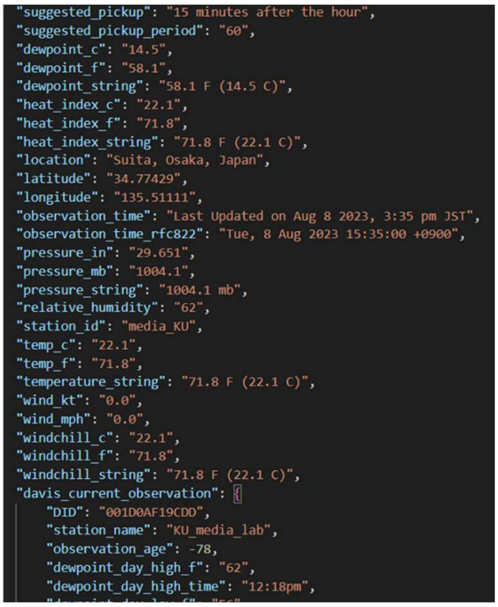

Fig. 7: Json data from Open Weather Map API (left)
and Json data from VantagePro2 (right)

The authors implemented a system that enables data acquired by a weather data collection server to be stored in a weather data database created in the relational database service (RDS) of AWS, a cloud service provided by Amazon, Inc. In addition to the basic meteorological information necessary for WBGT estimation, the database is designed to prevent data inconsistencies by setting latitude/longitude and place name information necessary for location identification as attributes. However, although wet-bulb temperature is required to calculate WBGT from Equation (1), some measurement equipment measures humidity instead of wet-bulb temperature. Open Weather Map API and VantagePro2 used in this paper do not measure wet-bulb temperature, so they calculate an approximation of wet-bulb temperature from humidity and dry-bulb temperature. If the equipment measures wet-bulb temperature, it is directly stored in the database, and if it cannot measure wet-bulb temperature, the system calculates an approximate value.

The 3D data collection server in the proposed system acquires extensive and detailed 3D city data publicly available, such as PLATEAU provided by the Ministry of Land, Infrastructure, Transport and Tourism in Japan. As a method of storing the acquired 3D data, we are considering a method for directly storing the data in a database or storing the 3D data in a cloud service such as Dropbox or Google Cloud Platform (GCP) and storing only a link to the destination in the database. In cases where open-source data is unavailable, we adopt a method of reconstructing 3D data from information sources such as 3D data from online map services such as Google Maps. The verification procedure is to set multiple waypoints in Google Maps, as shown in Fig. 8 (left), and create a KML file that contains geographic coordinate information to specify the route of the viewing viewpoint. By importing and executing the created KML file into Google Earth, it is possible to capture virtual aerial images that simulate UAV flight as shown in Fig. 8 (right), and through 3D reconstruction by SfM using photogrammetry, 3D data acquisition, as shown in Fig. 9, is realized. With the above implementation, obtaining the data necessary to generate a heat map is now possible using only the specific date, time, and location information entered by the user.

Fig. 8: Waypoints specified by our KML file depicted on Google Maps (Osaka: Suita, Japan) (left) and the captured virtual aerial photos through the waypoints in Google Earth (right)

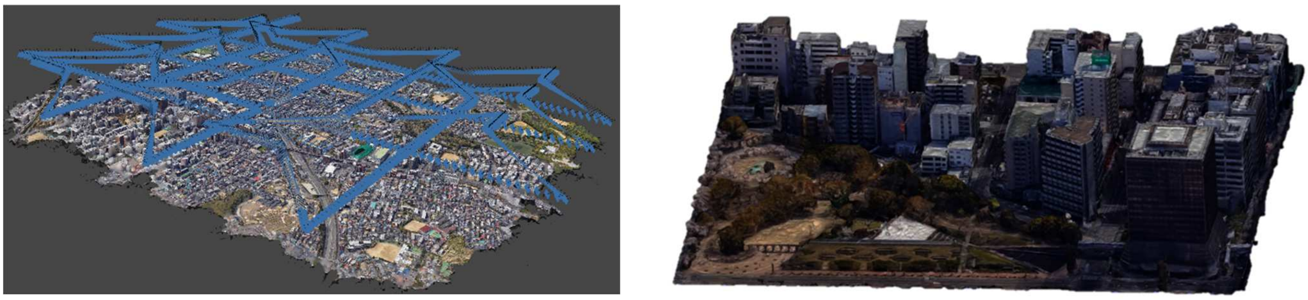

Fig. 9: 3D reconstruction based on SfM using the photo images in Fig. 8 (Osaka: Suita City, excerpts, Japan)

5. EXPERIMENTAL APPLICATIONS

5.1 Case Study in Shibuya and Shinjuku City, Tokyo

The following is an example of applying the proposed system to 3D data of Shibuya and Shinjuku city obtained from PLATEAU, a 3D data utilization service provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Furthermore, we show that the system can visualize the detailed distribution of heat stroke risk during the day and night by combining the system with time-dependent weather data stored in the weather information database, as shown in Fig. 10 and Fig. 11. At the time of writing this paper, the weather information for August 2023 was not available, so the data for August 11, 2022, was used for CG generation.

5.2 Examples of heat stroke risk prediction validation

During the Golden Week (early-May holiday season in Japan) of 2023, temperatures exceeding the average of 18.8°C announced by the Japan Meteorological Agency were observed. The maximum temperature in Tokyo on May 6 reached 27.9°C, which potentially increased the risk of heat stroke for people outside the city. This result shows that the risk of heat stroke in front of Shinjuku Station was at a level where it is recommended to actively hydrate oneself (Fig. 12). This result suggests that even during periods when the risk of heat stroke is generally recognized as low, the risk may still exist, and this system is an effective means of verifying this.

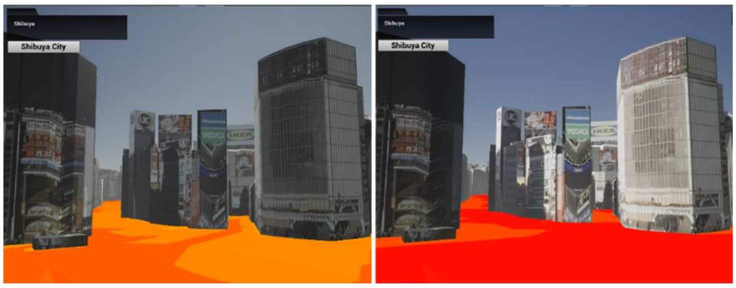

Fig. 10: Heat map of Shibuya City during the daytime
August 11, 2022, at 10:00 (left) August 11, 2022, at 14:00 (right)

Fig. 11 Heat map of Shinjuku City at night
August 11, 2022, at 18:00 (left) August 11, 2022, at 22:00 (right)

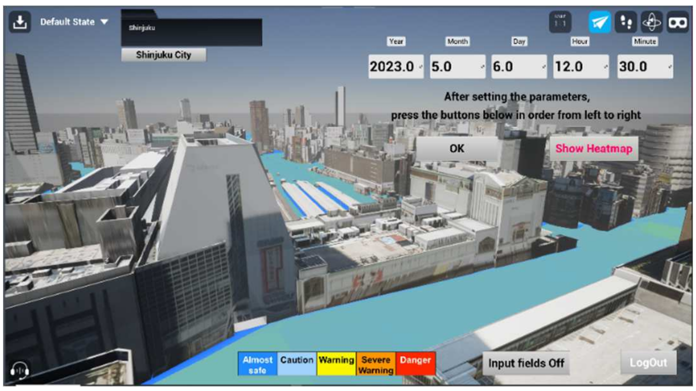

Fig. 12: Heat map of Shinjuku City during the day May 6, 2023, 12:30 p.m.

5.3 Case Study in Suita City, Osaka

For areas where open-source 3D data such as PLATEAU (see (1)) is not available, this method can be applied to 3D reconstruction using SfM from existing services such as Google Map's 3D view to generate a heat map as shown in Fig. 13. By importing kml files containing geographic coordinate information into Google Earth, it is possible to take aerial images that simulate UAV flights. We have shown that large-scale collection of 3D data is possible at low cost by using Google Earth to take comprehensive aerial photographs of surrounding areas.

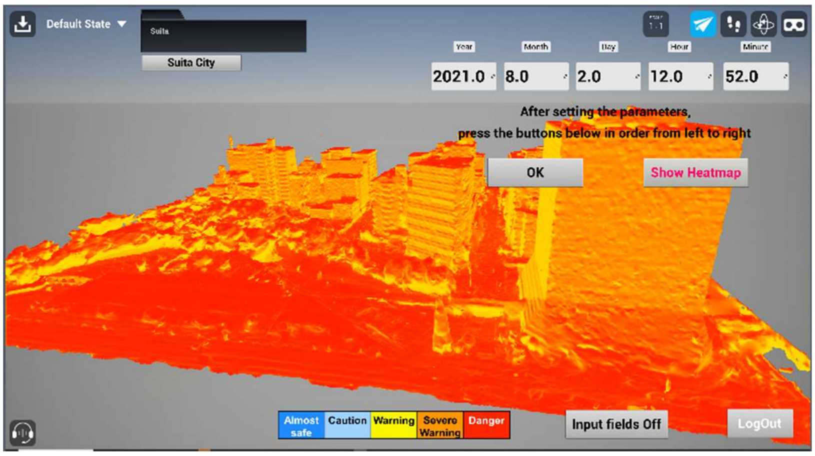

Fig. 13: Suita City: Heat Map
(3D reconstruction based on SfM), August 2, 2021, 12:52 PM

6. CONCLUSION

In our research, we developed a system that utilizes public weather information and 3D data using a game engine, enabling WBGT estimation and real-time heat maps for various regions and times. In the future, we aim to create a new solar radiation correlation equation that enables WBGT estimation on cloudy days based on weather information such as clear and cloudy skies obtained from meteorological data. In addition, the physical characteristics of 3D models of geological objects have yet to be considered. We plan to analyze the impact on WBGT by the reflectance and transmittance of surrounding buildings' surface materials and vegetation, considering the findings of prior CFD (computational fluids dynamics) studies. Incorporating the results of these analyses into the model will allow for a more accurate and realistic assessment of the thermal environment.

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REFERENCES

Ministry of Health, Labour and Welfare (1999~2020), Number of deaths due to heat stroke Vital Statistics (Fixed Number), https://www.mhlw.go.jp/toukei/saikin/hw/jinkou/tokusyu/necchusho20/dl/kenbetsu.pdf, (Getting 2023,8,9). (In Japanese)

Ministry of Internal Affairs and Communications (2022), Emergency medical evacuations due to heat stroke in 2022 (May to September), https://www.fdma.go.jp/disaster/heatstroke/items/r4/heatstroke_geppou_202205-09.pdf, p4, (Getting 2023,8,9). (In Japanese)

Ministry of Health, Labour and Welfare (2018-2022), Number of casualties due to heat stroke by time of day (2018-2022), https://www.mhlw.go.jp/content/11200000/000900487.pdf, p6, (Getting 2023,8,9). (In Japanese)

Ministry of the Environment (2022), Observation of the national heat index (WBGT) from September 26 to October 2, 2022, and the relationship between the WBGT and the number of emergency medical evacuees due to heat stroke (Report No. 23, FY2022),
https://www.wbgt.env.go.jp/pdf/R04_heatillness_report_23.pdf, (Getting 2023,8,9). (In Japanese)

T. Ozaki and H. Abe (2019), Analysis of Relationship between Usage Characteristics and Heat Environment in Parks for Health Promotion, Vol. 75, No. 6, pp. II-29-II-37. (In Japanese)

Ministry of the Environment (2022), Heat Stroke Prevention Website, https://www.wbgt.env.go.jp/en/

Ministry of the Environment, MEXT (2021), Guideline for the Preparation of Heat Stroke Prevention Guidelines for Schools (May 2021), https://www.mext.go.jp/content/210528-mxt_kyousei01-000015427_02.pdf, (Getting 2023,8,9). (In Japanese)

M.Okada, M. Okada and H. Kusaka (2013). Wide-area application and parameter adjustment of the Okada-Hisaka black-bulb temperature estimation equation, *Heat Island*, Vol. 8, pp. 13-21. (In Japanese)

Y. Yasumuro, K. Ichihara, Y. Nishiura, D. Ikegawa, M. Hayashi and T. Ozaki (2018), Estimation of WBGT using 3DCG and its application, *Journal of Civil Engineering G(Environment)*, Vol. 74, No. 6, pp. II-1-II-8. (In Japanese)

N. Sumida, T. Ozaki, S. Kubota, H. Dan, Y. Yasumuro (2022), Visualization of Environmental Heat Risks with Global Illumination in Game Engine, *Proceedings of the 22nd International Conference on Construction Application of Virtual Reality (CONVR2022)*, pp. 677-683.

SILVENNOINEN, A. and LEHTINEN, J. (2017): Real-time Global Illumination by Precomputed Local Reconstruction from Sparse Radiance Probes, *ACM Journals, ACM Transactions on Graphics*, Vol. 36, No. 6, pp. 1-13.

K. Kurachi (2007), CG Magic: Rendering, *Ohmsha,* 2007. (In Japanese)